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PRELIMINARY STRUCTURAL SIZING OF A MACH 3.0 HIGH-SPEED CIVIL TRANSPORT MODEL

Charles L. Blackburn

ANALYTICAL SERVICES & MATERIALS, INC.
Hampton, Virginia

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Langley Research Center
Hampton, Virginia 23665-5225

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1.0 Introduction

The development of future high-speed civil transport aircraft conceptual and preliminary designs requires the integration of inputs from all of the traditional aeronautics disciplines. An effort currently underway at NASA Langley Research Center to integrate these disciplines is focusing on the conceptual design of a High-Speed Civil Transport (HSCT) to provide a testbed for the development of the multidisciplinary methodology needed for future vehicle design. The success of this venture is dependent on the data management system used by the design system and its ability to interface with the various discipline-oriented application programs for the exchange of data in a fast and accurate manner.

Obviously, the development of a multidisciplinary, integrated design system is an immense task when considered overall, but the task is somewhat more manageable and the data requirements are more accurately defined when approached from a discipline level which acknowledges the inputs and outputs of the associated disciplines. These discipline oriented studies could be very informative when used in defining the application programs for the integrated system and the definition of the data base to support the input/output data requirements. In this regard, an analysis has been performed pertaining to the structural resizing of a candidate Mach 3.0 HSCT conceptual design using a computer program called EZDESIT (Ref. 1).

EZDESIT is a computer program which integrates the PATRAN finite element modeling program (Ref. 2) to the COMET finite element analysis program (Ref. 3) for the purpose of calculating element sizes or cross sectional dimensions. Bar, beam, and plate type structural elements are sized to support calculated stress resultants. The element sizing criteria consist of yield and ultimate strength, minimum gage, and local buckling constraints. The program is written in FORTRAN and operates on a CONVEX computer under a UNIX operating system with an interactive user interface. It is menu driven with interactive user queries which allows the user to translate PATRAN output to COMET input, structurally size the finite elements, and then translate the COMET output to a PATRAN postprocessing input. User instructions for menu selections and response to the interactive queries are given in Reference 1.

The purpose of the present report is to document the procedure used in accomplishing the preliminary structural sizing of a Mach 3.0 HSCT model and present the corresponding results. In describing the procedure, the data requirements are discussed in detail in order that they may be evaluated with respect to the data management goals of the vehicle design project. Furthermore, those modeling requirements unique to EZDESIT are documented as they relate to the creation of the finite element model by PATRAN (Ref. 2) since the PATRAN neutral file is required input for EZDESIT.

2.0 Foundation of Configuration and Aerodynamic Loads

The external configuration of the baseline Mach 3.0 HSCT aerospace vehicle concept used in the present investigation is fully described in Reference 4. This concept, shown in Figure 1, is a blended wing-body configuration with a modified platypus nose, a highly swept inboard wing panel, a moderately swept outboard wing panel, and curved wingtips. This configuration was primarily selected for structural modeling studies because it satisfies the aerodynamic and payload requirements necessary for efficient operation within the civilian air transportation industry. During this early phase of the conceptual design only minor consideration is usually given to structural problems (i.e., depth limitations due to slenderness and/or contouring of the external shape).

The aerodynamic loads are believed to be consistent with the load cases used for the study described in Reference 4 along with the associated baseline weights and performance data. These data are included in Table A-1 of Appendix A. A program called WINGDES (WING DESign) (Ref. 5) was used to compute the aerodynamic pressures for each of the load cases. Due to the limitations of WINGDES, only pressure distributions on the wing were considered in the analysis.

3.0 Description of Finite Element Model

A structural arrangement was generated within the confines of the external shape defined by Table IV of Reference 4 and, for the sake of completeness, is presented in Table B-1 of Appendix B. A modified version of the structural arrangement for the wing and fuselage configuration is shown in Figure 2. A brief discussion of the routine for creating this structural arrangement and its application to the generation of a wing structure is given in Reference 6. This arrangement was used to develop the PATRAN

Phase 1 geometry (grid points, lines, and patches) that is required for the generation of PATRAN Phase 2 geometry describing the nodes and elements of the finite element model. For this model, the network of lines and patches were defined by a set of grid points that occur at the intersection of the ribs and spars in the wing and the frames and longerons in the fuselage. Furthermore, the nodes of the finite element model were chosen to be coincident with the grid points of the geometrical model and, therefore, the representation of the finite elements is identical to the structural arrangement as shown in Figure 2.

(a) Structural Model

The structural elements of the finite element model consist of 577 rod, 229 beam, and 508 plate elements that are interconnected at their end or corner points by 398 nodes. The rod elements represent the caps and web stiffeners for the ribs and spars and the longerons of the fuselage. The beam elements represent the fuselage frames. The 508 plate elements are a combination of 32 triangular and 476 quadrilateral plates which are capable of representing both the membrane and bending stiffnesses of the cover panels for the wing and fuselage and the shear webs of the wing's ribs and spars. The triangular elements are required in modeling the rib structure at the leading and trailing edges of the wing and in some transition areas (i.e., wing-fuselage intersection and wing crank). The wing carry-through structure is a projection of the root rib and intersecting spars of the wing box through the fuselage in a direction normal to the airplane's plane of symmetry and is idealized accordingly. For convenience, the initial property identification numbers for each set of elements were assigned during this phase of model generation. The finite element model had a total of 2163 degrees of freedom.

Unique EZDESIT input requirements are satisfied during the formulation of the elements of the model; namely, assignment of a name or names to one or more structural components (i.e., wing upper surface, ribs, fuselage, etc.) and element numbering in the required sequence. EZDESIT requires that at least one component be assigned a name (Ref. 2, page 15-8) but good modeling procedures suggest naming all components in detail. For example, individual names are given to the wing's upper and lower surfaces, shear webs of the ribs and spars, and caps for the ribs and spars as opposed to giving a single name to the entire wing assemblage. This naming practice is particularly advantageous when assigning loads, constraints, and material and section properties. Furthermore, the elements contained in the PATRAN neutral file must be numbered consecutively beginning with the rods and continuing with the beams, triangular plates, and quadrilateral plates, respectively. If necessary, the elements can be renumbered using the PATRAN "RENUMBER" command given on page 5-28 of Reference 2. The number of each of these elements, which is required user input for the EZDESIT execution, is obtained using the PATRAN "SHOW, MAX2" command.

(b) Model Constraints

For computational efficiency, only half of the HSCT was modeled and boundary constraints were applied to the nodes in the plane of symmetry to represent the remaining half. The rigid body motions were restrained by applying the necessary constraints to those nodes of the wing carry-through structure that lie in the airplane's plane of symmetry (namely; constraints in the Z-direction at two nodes along the X-axis to prevent vertical and pitching motion and a single constraint in the X-direction to prevent axial motion).

(c) Material and Section Properties

This initial study is based on two finite element models composed entirely of 2024-T81 aluminum or Ti-6Al-4V titanium, respectively. The resizing routine used in this study is presently restricted to structural components made of isotropic materials. However, in order to increase the stiffness of the aircraft structure, a minor modification was made to the finite element model and the modulus of the aluminum material was increased without any considerations of the other physical characteristics (i.e., specific weight, strength allowables, etc.). The modification of the finite element model involved only a change of the spar cap properties from the aluminum material to a generic graphite-epoxy system whose properties were available in the materials data base file. For the material modifications, the major modulus of elasticity (E_{11}) for the Hercules IM7/8552 graphite-epoxy system replaced the modulus of elasticity for the aluminum and, in another case, a "future improved material" with the modulus of elasticity of steel was used. In both cases, the Poisson's ratio and specific weight of aluminum was retained. The pertinent characteristics for each of these materials are presented in Table 1. The EZDESIT routine requires that the properties of each of these materials be contained in a file called "matprop.prn" which resides in the execution directory and contains the data of Table 1 along with other physical characteristics such as strength allowables. Since the material properties are temperature dependent, a temperature is assigned to each element (for the present study, the entire vehicle is assumed to be at room temperature, 72 deg. F) using the PATRAN "DFEG" command given on page 22-12 of Reference 2.

The section properties for each of the elements in the finite element model represent the actual structural component (i.e., idealization of an integrally stiffened panel as a plate element). The lower bound of these section properties is dictated by the minimum gage requirements for fabricating and assembling the structural components. For the present model, the characteristic section properties for the elements used to idealize the structural components are defined as follows:

> The rod elements representing the rib and spar caps and the longerons of the fuselage are sized by their cross-sectional area.
>
> The beam elements representing the frames of the fuselage are sized by the cap or flange area, web height, and web thickness.
>
> The plate elements representing the skins or surface panels of the wing and fuselage are idealizations of honeycomb panels and are sized by facesheet thickness and core height.
>
> The plate elements representing the webs of the ribs and spars are idealizations of corrugated panels and are sized by the thickness of the material.

The minimum gage values for the elements used in the present model are listed below.

Rod	Area = 0.01 sq. in.
Beam	Cap Area = 0.5 sq. in. Web Height = 2.0 in. Web Thickness = 0.1 in.

Honeycomb Panel	Facesheet Thickness = 0.01 in. Minimum Core Height = 0.1 in. Maximum Core Height = 3.0 in.
Corrugated Panel	Web Thickness = 0.01 in.

To size the elements with EZDESIT, each unique set of finite elements (i.e., those elements fabricated in the same way and of the same material, such as an aluminum corrugated shear web) must be assigned a set of physical property data which specifies the necessary design parameters such as the minimum gage sizes shown above. These data must be specified during the formulation of the model with PATRAN which can be accomplished using the "ADD" option of the PATRAN "PROPERTY" command given on page 19-23 of Reference 2. The required order of input for these parameters and their magnitudes, as used in this study, are excerpted from Reference 1 and presented in Appendix C.

(d) <u>Distribution of Non-Structural Weight</u>

The defined weight properties are primarily based on interpretations of historical data as it may relate to the HSCT. The magnitudes of the non-structural weights and locations of their center of gravity is given in Table II of Reference 4 and has been reproduced as Table B-2 in Appendix B. The distribution of this non-structural weight was derived from an earlier drawing of the internal arrangement of the primary components (fuel tanks, passenger seating, landing gears, etc.) as reproduced in Figure 3. Although the maximum gross weight of Reference 4 differs from the flight weights corresponding to the design load conditions given by Table A-2 of Appendix A, the ratio of the non-structural weights to the maximum gross weight, as given in Reference 4, has been retained. Using this ratio to obtain the flight design gross weight for a particular load case was expedient, but it did not address the issue of weight distribution to assure a trimmed or balanced airplane and was probably an unrealistic ratio for most weight items except fuel.

A weighting routine was used in the present study to distribute the weight of a particular non-structural item to those nodes of the finite element model within the vicinity of the item's center of gravity. The affected nodes were visually selected using the layout of Figure 3 and/or the center of gravity position given in Table II of Reference 4 (Table B-2 of Appendix B). For the selected nodes, the routine calculates and assigns a larger portion of a particular item's weight to those nodes nearest its center of gravity with a proportional decrease in the amount of weight assigned to those nodes further away. The equation used to obtain the weight distribution for the non-structural items is as follows:

$$W_i = (W/n)[1 - (l_i - l_{av})/(l_{max} - l_{min})]$$

where

W_i	weight of item assigned to node i,
W	total weight of item,
n	number of effected nodes,
l_i	distance of node i from CG in X-Y plane,
l_{av}	$(1/n) \sum_{i=1}^{n} l_i$
l_{max}	the distance of the node furtherest from the CG,
l_{min}	the distance of the node closest to the CG.

These nodal weights are assigned to the model using the PATRAN "DFEG" command for associating temperatures (scalars) with nodes (Ref. 2, page 22-12). The EZDESIT routine interprets the corresponding data in the PATRAN neutral file as concentrated weights.

(e) <u>"Remeshing" of Aerodynamic Pressures</u>

A computer routine was developed for converting the aerodynamic pressure data into a PATRAN neutral file describing the nodes and mesh of the aerodynamic model and the magnitude of the pressure acting at each node (nodal pressures). PATRAN requires that this neutral file be converted from a ASCII text file to a binary file. A PATRAN utility program called "reader" (Ref. 2, page 1-23) can be used for this conversion. The pressure distribution corresponding to a load case superimposed on the mesh of the aerodynamic model is shown in Figure 4.

A PATRAN routine for mapping nodal temperature constraints in a global-to-local (or vice versa) application was utilized (Ref. 2, page 22-25a) to map the pressure data of the various load cases onto the structural mesh of the finite element model. One of this routine's interactive request for input is the name of the PATRAN neutral file which is the name of the binary file discussed above. PATRAN recognizes these pressure data as nodal temperature data and they are reflected as such in the current PATRAN neutral file that is generated. The temperature data are converted into pressure data during the EZDESIT execution which is described below.

(f) EZDESIT Requirements

Since EZDESIT accepts only element temperature data as input, the nodal temperatures contained in the PATRAN neutral file, discussed above, were converted to element temperatures using an interactive program developed for this purpose. Options contained in the program allow for assigning element temperatures to any or all of the named components discussed in Section 3.0 (a). This program then creates a new neutral file which must be called "patran.out" due to EZDESIT input specifications.

4.0 EZDESIT Execution

(a) Generation of the COMET Runstream

EZDESIT is a menu driven program with interactive queries which culminates into a COMET runstream. The first user response, prior to the appearance of the menu, is for the number of bars, beams, triangular plates, and quadrilateral plates (in this order) which is

577 229 32 476

for the present finite element model. The program's main menu then appears on the screen and is reproduced below, for clarity, since it is similar, but not identical, to that menu documented in Reference 2.

1 - Create a COMET runstream through XQT INV
2 - Not available
3 - Create a partial COMET runstream
for applying/combining loads and constraints
4 - Update COMET element stiffness matrices
5 - Translate COMET results to PATRAN results files
6 - Run element sizing code
7 - Create worst case dimension file
8 - Review calculated component weights
9 - Exit to system

The initial selection of menu item 1 translates the nodal locations, element connectivity, constraint cases, and nodal weights from the PATRAN neutral file (patran.out) into a COMET runstream. Also, dummy data are inserted into the runstream for the material and section properties and nonstructural weights. The so-called "nonstructural weights" represent the weight of the individual structural finite elements. Next, menu item 6 is selected to create the initial unit weight file, called "uwtmin.out", and dimension file, called "ldstmin.dim", for the elements which are based on the specified material(s) and minimum gage sizing contained in the PATRAN neutral file. The material data are contained in a file called "matprop.prn". Menu item 4 is then selected to create initial element stiffnesses based on the dimension files generated by execution of menu item 6 and the physical characteristics of corresponding materials which are used to update the dummy data created under menu item 1. These element stiffnesses are generated by a program called STIMAT which has been incorporated as a subroutine in the EZDESIT procedure. Finally, selection of menu item 3 converts PATRAN applied load information to a COMET applied load format, sets up inertial load cases described by the analyst, and combines several load cases to define a design load condition. This information and data are then assembled into a portion of the COMET runstream that can include processors for generation of stress resultants and nodal displacements files. Selection of menu item 9 returns the user to the operating system.

At this point, it is necessary to edit the runstream file created by menu item 3 to accomplish the following:

Remove the system commands contained in the first four lines of the COMET runstream.

The following statement is included immediately after entry into the E processor since most quadrilateral plate elements used for modeling the the wing and fuselage cover panels exceed the default element warping (i.e., not all four nodes in a plane) limits of the COMET program.

T= 1.-20, .05, 1.-5, 1.-1, 20., 1.-4, 1.-4, 1.-4

Although excessive warping does not produce a fatal error, a notice of failure is written into the log file at each occurrence and the revision of the fourth term from its default value of 1.0×10^{-5} to the indicated value of 1.0×10^{-1} will substantially reduce this output.

Insert "eldata: pres exx sid 1" for the present study at the appropriate locations where PATRAN element temperature data were used to represent element pressure data. (The "xx" of exx is the element number such as e43 or e33 and "sid" is the load case number.)

Due to an EZDESIT formatting error, the "summing" statement for combining the aerodynamic pressures and the inertial loads requires editing.

Move to the end of the runstream file and insert "[XQT EXIT".

This edited version of the loads and solution portion of the COMET runstream is merged at the end of the runstream created by menu item 1 for a complete runstream that can be submitted for batch execution of the element sizing process. An abbreviated listing of a runstream for the all-titanium finite element model is presented in Appendix D. As will be indicated in the next section, this runstream (file) is called "tb.dat".

(b) <u>Batch Submittal of the COMET Runstream</u>

The EZDESIT program creates a COMET runstream, but the iterative procedure for resizing the structure is accomplished using a program called EZBATCH. The EZBATCH program accesses the COMET system and submits the COMET runstream (tb.dat) by calling a command (script) file called "tb.scr". (If the name of the runstream is other than "tb.dat", "tb.scr" must be modified to reflect this new name.) A listing of "tb.scr" follows:

```
#/!bin/csh -f
source /csm/login
testbed <tb.dat
```

Another file called "ezbatch.dat" must be created. This file defines the load sets, constraint sets, associated thermal load sets, and associated element temperatures that are used for the iterative resizing process. A description of the contents of this file is given in Reference 2 and a listing of the file as it relates to the present study follows:

```
577 229 32 476
5
51 52 53 61 62
1 1 1 1 1
0 0 0 0 0
0 0 0 0 0
0 0 0 0 0
1 1 1 1 1
5
```

Next, a copy of the file called "ldstmin.dim" (created during execution of menu item 6) is copied to a file named "ldstcomb.dim;00" which is used for creating a worst-case element dimension file. Finally, the program "EZBATCH" is submitted as a batch job to initiate the element sizing process. A typical UNIX command for submitting the job is

```
ezbatch >& ezbatch.out &
```

which assumes the program execution file resides in the current working directory. The file "ezbatch.out" contains iteration information and is created as the EZBATCH execution proceeds.

5.0 Design Cycle

(a) Load Iterations for Balanced Airplane

For the initial structural resizing, the airplane was not balanced for free flight which usually results in large boundary reactions at the fictitious boundary constraints. This imbalance was unavoidable due to the unavailabilty of the "true" structural weight prior to structural sizing and, consequently, the magnitude of the resultant lift component required to balance and trim the airplane. Once the structure was resized for all five design load conditions, an iterative process was carried out to balance the aerodynamic pressure loads with the inertial forces (structural and non-structural weights). A control force was applied at the aft end of the airplane to counteract the moment caused by the difference in the center of gravity and the center of pressure for each of the five design load cases. Usually, two iterations were required to obtain a nearly balanced airplane (which minimized the boundary reactions) after the resultants of the aerodynamic pressure loads and the inertial forces were balanced. The lift component of the aerodynamic load was increased or decreased to compensate for the vertical balance load. A detailed description of this balancing process is given in Appendix E for a typical design load condition.

(b) Resizing Iterations

In the course of obtaining a balanced airplane for the initially sized structural elements, it was necessary to modify the applied loads and weights. For the present study, a second resizing of the structural elements was performed only on the all-titanium finite element model. This resizing involved another execution of the EZDESIT program to incorporate the new applied forces and to create a new COMET runstream. However, the experienced user can avoid a complete re-execution of EZDESIT by carefully editing the COMET runstream and relocating or renaming the output files from the initial EZBATCH execution.

6.0 Results

The initial structural resizing results for the all-aluminum finite element model of the candidate Mach 3.0 HSCT yielded large wing tip displacements. These large displacements are primarily due to the small depth of the external shape of the wing and secondarily due to the small number of spars and their arrangement within the wing. Variations of the external shape or the structural arrangement to obtain increased stiffness was not done for this initial investigation because of the excessive time required to generate a new finite element model. However, variations of the structural stiffness were obtained by using different materials. The various non-metallic materials considered were based entirely on the major modulus of elasticity of the composite laminates and the resizing algorithm was based on the failure criteria and manufacturing requirements (i.e., minimum gage) of metallic materials and their associated allowable design strengths.

(a) Weight

The structural weights of the finite element models for the various materials considered are shown in Table 2. These structural weights do not include a significant portion of the structural weight due to fasteners, splices, shims, etc. A second resizing iteration of the all-titanium model resulted in a structural weight increase of nearly 13%. This weight increase is probably due to the increase in lift on the wing that was required to obtain a balanced airplane and resulted in higher internal loads, particularly at the wing-fuselage intersection. No aerodynamic forces were applied to the fuselage and the aerodynamic forces were applied to the wing's lower surface. A third iteration resulted in a negligible change of this weight.

(b) Stiffness and Deflection

A comparison of the maximum wing tip deflection (at the trailing edge of the tip rib) corresponding to the various design load cases and the finite element models composed of various materials is presented in Table 3. The resizing algorithm did not include a deflection (or stiffness) constraint which resulted in the large wing tip deflections for this primarily strength designed structure with minimum gage constraints. Of course, increasing the elastic moduli of the materials will produce smaller deflections. But stiffening the spar caps using a graphite-epoxy material for an otherwise all-aluminum model resulted in little or no change in the deflections. The ineffectiveness of the stiffened spar caps is due to the fact that the overall stiffness effects (i.e., EA, EI, and GJ) of the wing skins are so much greater than the stiffness contributed by the spar caps. There was no variation of the minimum gages for the present study.

The deflections resulting from another resizing iteration of the all-titanium model with the new balance loads indicated a decrease in the tip deflection of approximately 30%. This decrease in tip deflection was probably due to the decreased wing loading (caused by compensating for the balance load) and the relieving effect of the increased structural weight. Another resizing iteration for this model showed little, if any, change in the wing tip displacement.

The quadrilateral elements representing the cover panels of the wing and fuselage are excessively warped with respect to the element specifications of COMET. The effect of this warping on the shape of the deformed structure is not known; however, results presented in Reference 7 indicated small but significant effects (4% to 7%) on the displacement of a simple, cantilevered, box-beam structure.

7.0 Concluding Remarks

A structural sizing study for a single configuration of a candidate Mach 3.0 High-Speed Civil Transport has been conducted. An integrated analysis system incorporating routines to generate structural arrangements (and corresponding finite element models) along with the routines used herein provide a design tool that is both timely and cost effective for performing such analyses. In this regard, a detailed description of the procedures used and the data handling tasks performed during the execution of this study have been included in this report to facilitate the implementation of a structural sizing procedure into such a system.

The wing tip displacements are excessive for all materials considered for the finite element model used in the study. Major increases in stiffness will only be obtained by increasing the depth and/or rearranging the internal structure (ribs and spars) of the wing. Significant increases in stiffness can be obtained by using structural components made of composite materials; however, the present version of EZDESIT is limited to the resizing of structural components made of isotropic materials. Furthermore, the increased strength of the composite materials would result in a lighter vehicle; hence, reduced loads. Finally, refinement of the displacements can be obtained by evaluating the effect of the warped plate elements and mesh refinements.

8.0 References

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Table 1 - Physical characteristics of the materials used in the present study.

Material	Modulus of Elasticity, msi	Poisson's Ratio	Specific Weight, lbs/in.^{3}
2024-T81 Aluminum	10.0	0.33	0.100
Ti-6-4 Titanium	16.0	0.31	0.160
IM7/8552* Graphite-Epoxy	24.5	0.33	0.100
Generic Graphite-Epoxy	19.3	0.30	0.058
Future Improved Material	30.0	0.33	0.100

* Product of Hercules Materials & Systems Company

Table 2 - Comparison of the structural weight for finite element models composed of various materials.

Material	Structural Weight, lbs
Design Iteration 1	
Titanium	34,256.8
Aluminum	35,871.8
IM7/8552	32,272.2
Future Improved Material	31,680.6
Aluminum with Graphite-Epoxy Spar Caps	35,812.0
Design Iteration 2	
Titanium	38,657.4
Design Iteration 3	
Titanium	38,684.4

Table 3 - Comparison of the maximum wing tip displacement for the design load cases with finite element models composed of various materials.

Finite Element Model	Wing Tip Displacements, inches				
	Case 1	Case 2	Case 3	Case 4	Case 5
	Design Iteration 1				
Titanium	220.0	251.0	144.0	640.0	667.0
Aluminum	179.0	199.0	116.0	520.0	537.0
IM7/8552	76.7	84.7	49.4	223.0	229.0
Future Improved Material	63.5	70.1	40.9	184.0	190.0
Aluminum with Graphite-Epoxy Spar Caps	180.0	199.0	116.0	521.0	537.0
	Design Iteration 2				
Titanium	158.0	177.0	102.0	458.0	472.0
	Design Iteration 3				
Titanium	158.0	176.0	102.0	457.0	471.0

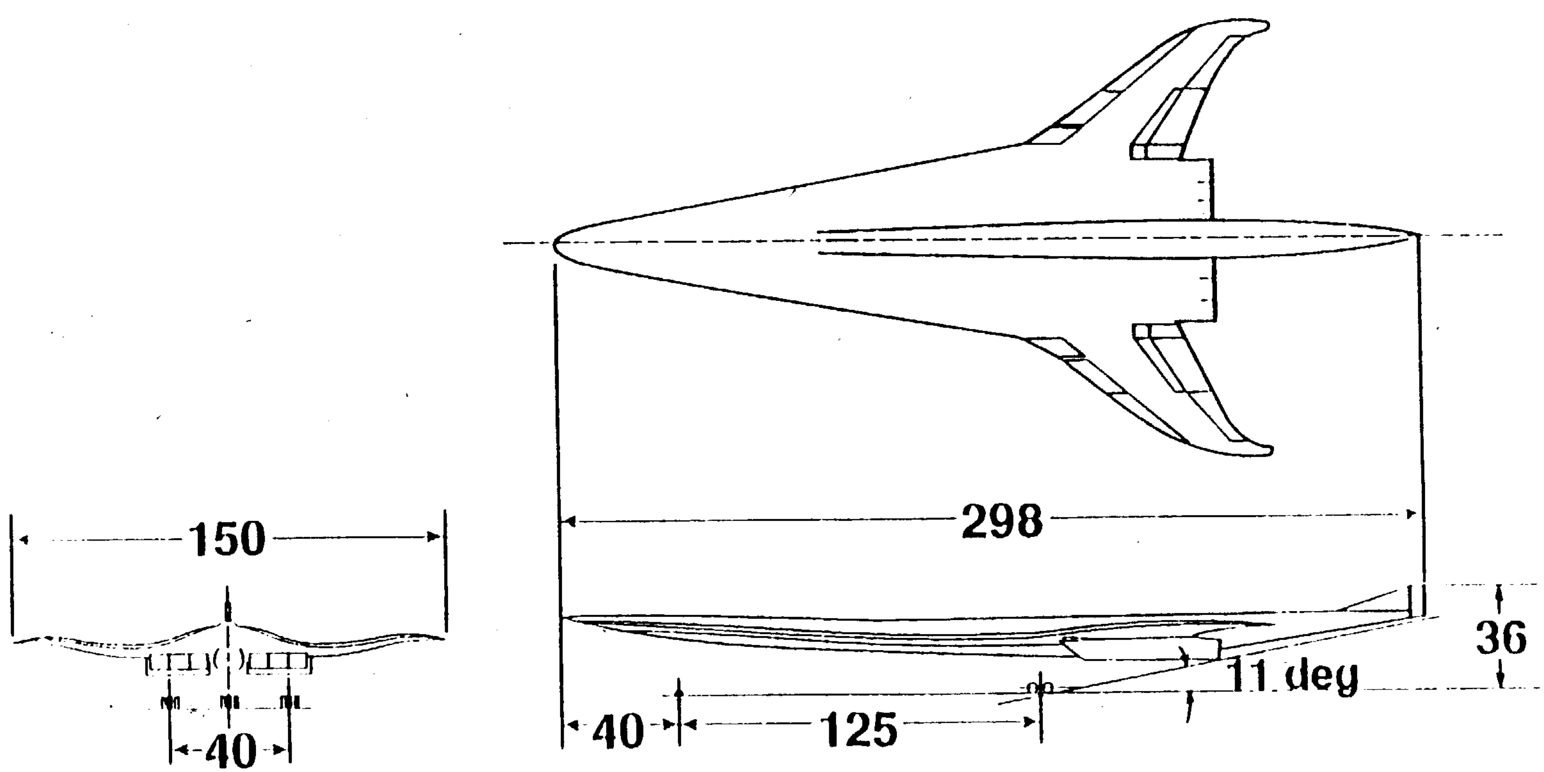

Figure 1. General arrangement of a Mach 3.0 High-Speed Civil Transport (ref. 4). Linear dimensions are in feet.

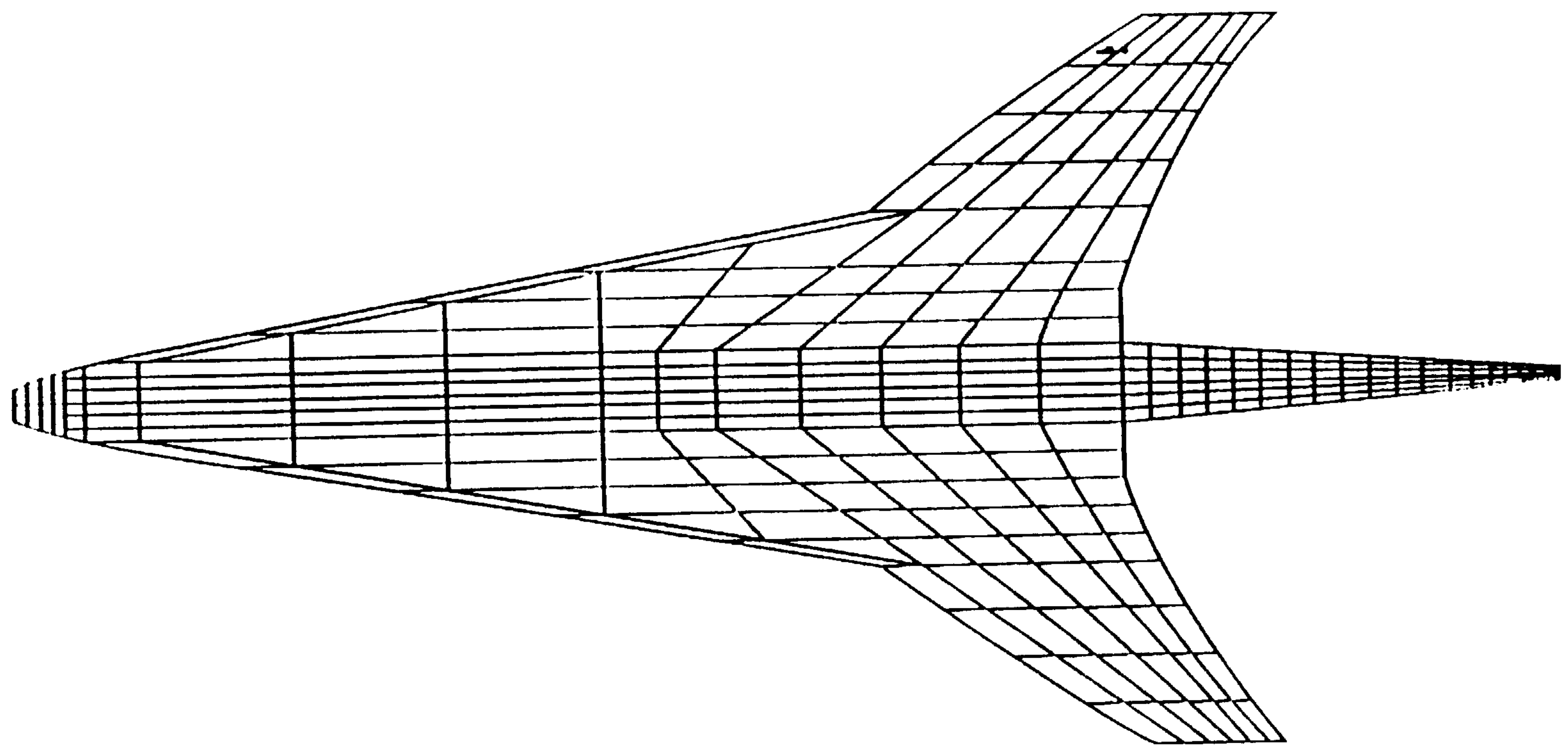

Figure 2. Structural arrangement and finite element model.

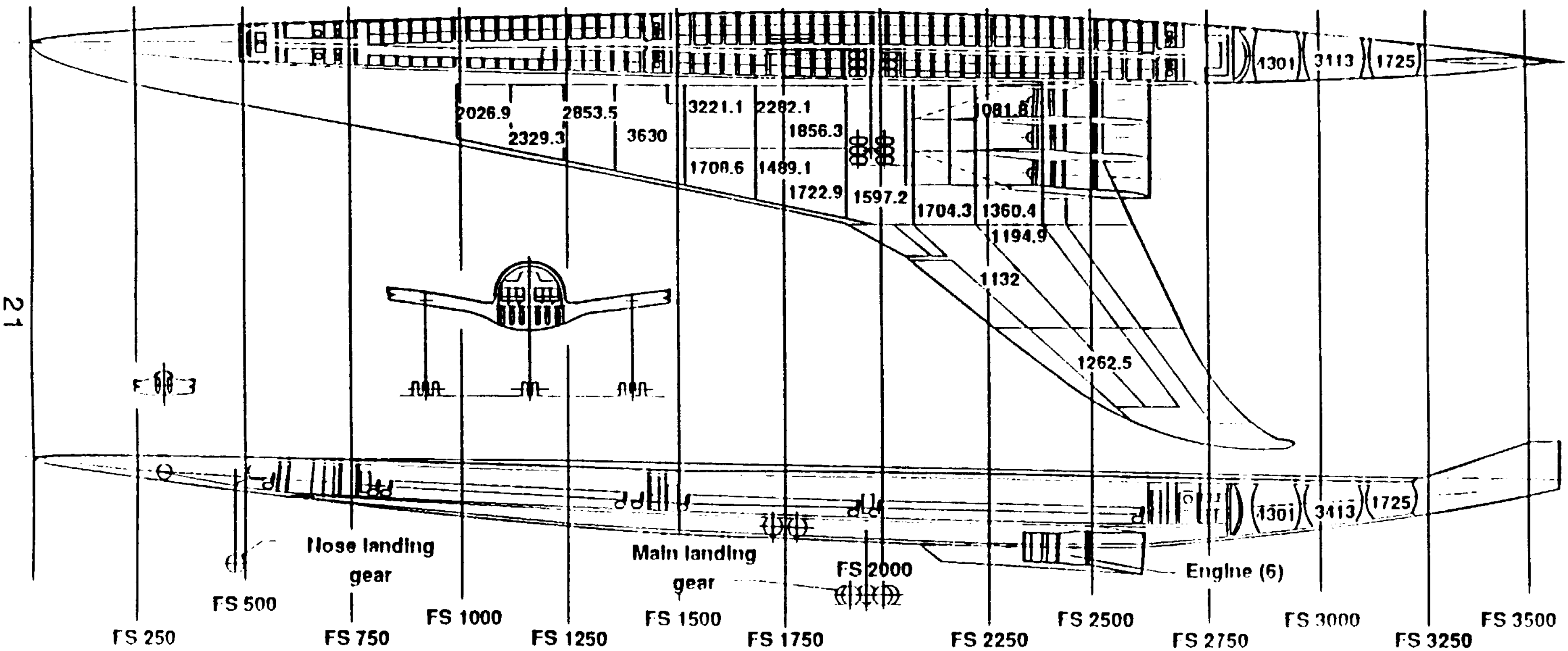

Figure 3. Internal arrangement of primary non-structural weight items. The maximum fuel weight (lbs.) of the various tanks is indicated.

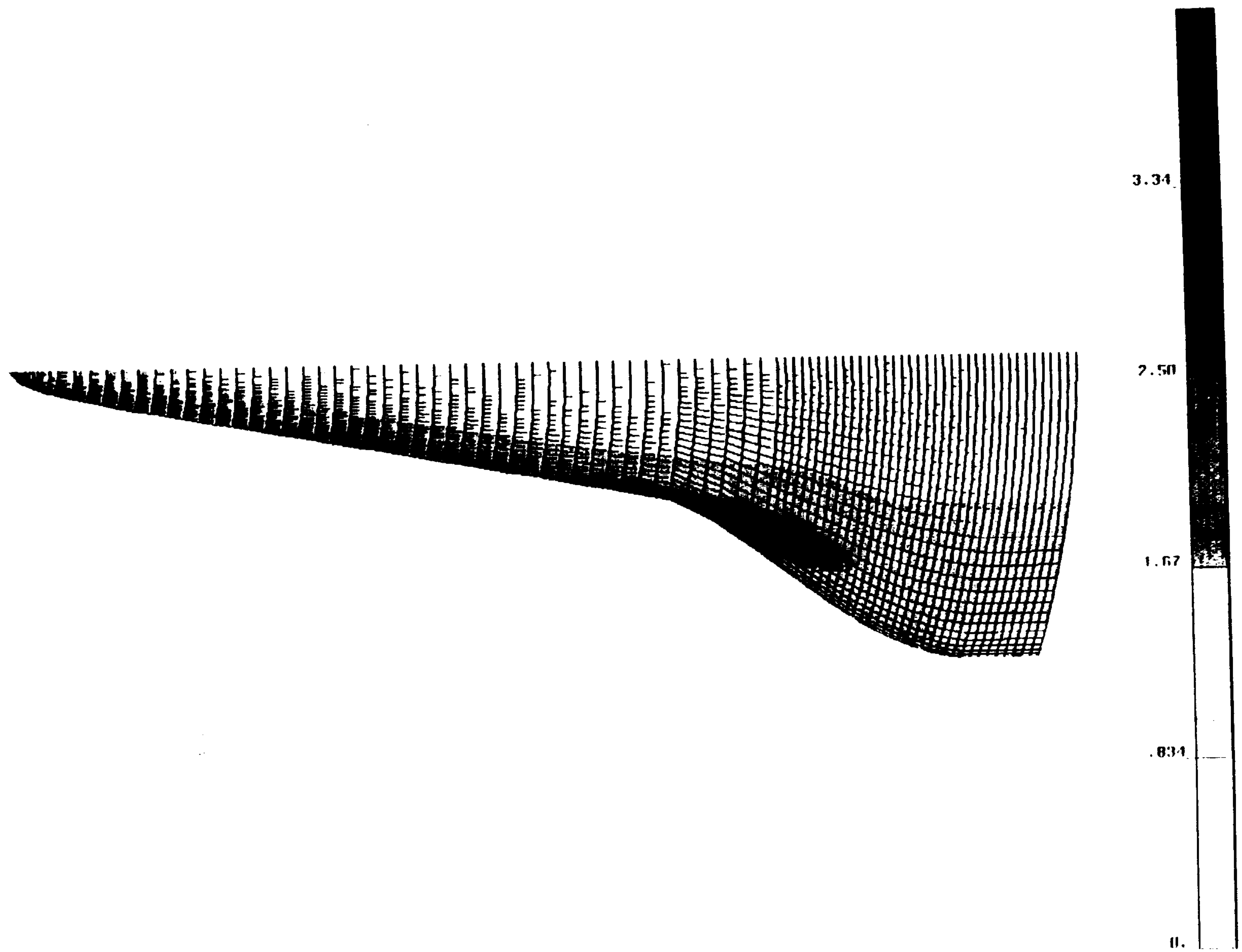

Figure 4. Pressure distribution superimposed on the mesh of the aerodynamic model.

Appendix A

Weight Summary and Design Flight Loads for a Candidate Mach 3.0 High-Speed Civil Transport

The baseline flight load cases used for determining the aerodynamic and inertia loadings for the present study are given in Table A-1. These flight conditions were based on trajectory optimization studies for a version of the HSCT whose weight breakdown is presented in Table A-2.

Table A-1 - Baseline flight load cases for a candidate Mach 3.0 HSCT.

Load Case	Mach Number	Altitude, ft.	Load Factor, g's	Flight Weight, lbs	C_L	Comments
1	3.0	72,700	1.0	494,000	0.077	Mid cruise
2	1.2	21,300	1.0	656,000	0.058	Transonic climb
3	0.9	43,000	1.0	333,000	0.141	Reserve cruise
4	3.0	59,000	2.5	623,000	0.127	Structural limit at cruise Mach number
5	0.6	10,000	2.5	664,000	0.363	Structural limit at low speed

Table A-2 - Weight summary for a version of a candidate Mach 3.0 HSCT.

ITEM	WEIGHT, lbs	
Wing	76974	
Horizontal Tail	0	
Vertical Tail	554	
Canard	0	
Fuselage	43906	
Landing Gear	22615	
Nacelles	18440	
Total Structure		162489
Engines	23096	
Thrust Reverser	0	
Propeller	0	
Gear Box	0	
Miscellaneous Systems	1508	
Plumbing	5694	
Tanks	0	
Insulation	0	
Total Propulsion		30298
Surface Controls	9240	
Auxillary Power	1210	
Instruments	1410	
Hydraulics	5526	
Electrical	4170	
Avionics	1732	
Furnishings and Equipment	20302	
Air Conditioning	7827	
Anti-icing	274	
Total Systems and Equipment		51691

Table A-2 - Con't.

ITEM	WEIGHT, lbs	
EMPTY WEIGHT		244478
Flight Crew	450	
Cabin Crew	1130	
Unusable Fuel	3636	
Engine Oil	545	
Passenger Service	3560	
Cargo Containers	7162	16483
Total Operating Weight		260961
OPERATING EMPTY WEIGHT		
Passengers (250)	41250	
Baggage	11000	
Cargo	2565	
Total Payload		54815
Zero Fuel Weight		315776
Mission Fuel Weight		359924
MAXIMUM GROSS WEIGHT		675700

Appendix B

External Shape and Mass Properties for a Baseline Mach 3.0 HSCT Concept

The finite element model used in the present study was generated within the external shape of a baseline HSCT concept defined in Reference 4 and is reproduced herein as Table B-1. The distribution of the non-structural mass for this finite element model was based on empirically estimated weight and balance data for this baseline concept as given in Table B-2

Table B-1 - Numerical model for the external shape of a baseline Mach 3.0 HSCT concept.

```
      2ABT3I  FUSELAGE AS WING ANLZ/SUBAERF MODEL INCLUDING PODS
                                                        5 10
 1  1  0  1  0  0  2 14 20                                                  SCXCG
12185. 129.70 160.0                                                         XAF1
0.0     .50    .75     1.25    2.50    5.00    7.50    10.0    15.0    20.0     XAF2
25.0    30.0   35.0    40.0    50.0    60.0    70.0    80.0    90.0    100.0    WORG   1
0.0     0.0    0.0     209.147                                              WORG  1A
1.163   2.0    -.70    207.984                                              WORG   2
7.270   5.0    -1.70   201.877                                              WORG   3
16.358 7.5     -2.60   192.789                                              WORG   4
25.333 9.333   -3.57   183.814                                              WORG   5
56.096 15.00   -4.80   153.052                                              WORG   6
83.238 20.00   -6.69   125.909                                              WORG   7
121.23827.00   -8.28   91.110                                               WORG   8
160.33334.202  -9.00   55.309                                               WORG   9
171.33340.00   -8.00   47.281                                               WORG  10
188.66753.00   -6.47   36.725                                               WORG  11
210.49568.00   -5.60   25.150                                               WORG  12
219.63872.00   -5.90   21.320                                               WORG  13
238.40 75.30   -6.00   8.400  -0.368  -0.811  -1.261  -1.698  -2.478  -3.117   ZORD 1-1
  0.000 -0.069 -0.102 -0.176  -5.933  -6.583  -7.160  -7.704  -8.219  -8.716   ZORD 1-2
 -3.700 -4.250 -4.750 -5.196  -0.368  -0.811  -1.262  -1.718  -2.560  -3.288   ZORD1A-1
  0.000 -0.069 -0.102 -0.176  -6.075  -6.680  -7.226  -7.741  -8.230  -8.731   ZORD1A-2
 -3.927 -4.480 -4.939 -5.366  -0.190  -0.480  -0.832  -1.211  -2.059  -2.395   ZORD 2-1
  0.000 -0.028 -0.044 -0.079  -6.241  -6.800  -7.254  -7.671  -8.079  -8.465   ZORD 2-2
 -3.685 -4.420 -5.009 -5.487   0.052  -0.150  -0.147  -0.767  -1.575  -2.392   ZORD 3-1
  0.000  0.027  0.037  0.052  -6.292  -7.133  -7.775  -8.259  -8.533  -8.751   ZORD 3-2
 -3.158 -3.908 -4.625 -5.275   0.160   0.217   0.037  -0.202  -0.798  -1.487   ZORD 4-1
  0.000  0.031  0.048  0.075  -5.163  -5.968  -6.603  -7.082  -7.436  -7.739   ZORD 4-2
 -2.209 -2.917 -3.534 -4.132   0.286   0.484   0.545   0.504   0.300  -0.049   ZORD 5-1
  0.000  0.064  0.096  0.155  -2.983  -3.946  -4.803  -5.525  -6.087  -6.460   ZORD 5-2
 -0.467 -0.943 -1.442 -1.959   0.295   0.510   0.638   0.700   0.690   0.570   ZORD 6-1
  0.000  0.065  0.097  0.157  -1.260  -2.001  -2.722  -3.395  -3.990  -4.475   ZORD 6-2
  0.358  0.105 -0.206 -0.540   0.247   0.452   0.614   0.725   0.841   0.880   ZORD 7-1
  0.000  0.053  0.078  0.128   0.292  -0.094  -0.507  -0.923  -1.326  -1.697   ZORD 7-2
  0.887  0.831  0.730  0.606   0.112   0.218   0.320   0.418   0.550   0.614   ZORD 8-1
  0.000  0.023  0.034  0.056   0.764   0.786   0.806   0.324   0.827   0.830   ZORD 8-2
  0.649  0.682  0.704  0.726   0.011   0.021   0.030   0.039   0.054   0.066   ZORD 9-1
  0.000  0.002  0.003  0.005   0.134   0.144   0.150   0.149   0.151   0.140   ZORD 9-2
  0.077  0.089  0.103  0.114  -0.029  -0.057  -0.084  -0.111  -0.162  -0.209   ZORD10-1
  0.000 -0.006 -0.009 -0.015  -0.437  -0.487  -0.521  -0.537  -0.544  -0.548   ZORD10-2
 -0.253 -0.295 -0.335 -0.372  -0.008  -0.017  -0.025  -0.032  -0.048  -0.063   ZORD11-1
  0.000 -0.002 -0.003 -0.004  -0.147  -0.168  -0.181  -0.188  -0.190  -0.187   ZORD11-2
 -0.078 -0.093 -0.107 -0.120   0.000   0.000   0.000   0.000  -0.001  -0.002   ZORD12-1
  0.000  0.000  0.000  0.000  -0.020  -0.027  -0.036  -0.043  -0.044  -0.040   ZORD12-2
 -0.004 -0.006 -0.008 -0.011   0.001   0.002   0.002   0.003   0.005   0.006   ZORD13-1
  0.000  0.000  0.000  0.000   0.016   0.019   0.022   0.025   0.028   0.031   ZORD13-2
  0.008  0.009  0.011  0.013
```

Table B-1 - Con't.

0.0	.10	.14	.23	.44	.79	1.07	1.30	1.72	2.05	WORD 1-1
2.25	2.41	2.56	2.68	2.83	2.97	3.43	3.70	3.55	2.69	WORD 1-2
0.0	.08	.14	.20	.37	.62	.78	.92	1.34	1.70	WORD 1A1
1.96	2.17	2.33	2.49	2.68	2.83	3.17	3.29	2.92	2.33	WORD 1A2.
0.0	.08	.12	.21	.30	.41	.50	.59	.70	.86	WORD 2-1
1.08	1.31	1.58	1.93	2.33	2.29	1.97	1.68	1.41	1.04	WORD 2-2
0.0	.061	.108	.182	.287	.405	.488	.562	.685	.793	WORD 3-1
.886	.953	.990	.996	.994	.962	.838	.586	.283	0.0	WORD 3-2
0.0	.1333	.1599	.2037	.2970	.4151	.5017	.5741	.6893	.7788	WORD 4-1
.8473	.8987	.9330	.9511	.9330	.8340	.6731	.4656	.2352	0.0	WORD 4-2
0.0	.1424	.1709	.2177	.3174	.4435	.5631	.6134	.7365	.8322	WORD 5-1
.9054	.9603	.9970	1.0163	.9970	.8912	.7192	.4975	.2513	0.0	WORD 5-2
0.0	.1573	.1887	.2404	.3505	.4898	.5921	.6774	.8134	.9190	WORD 6-1
.9999	1.0605	1.1010	1.1223	1.1010	.9841	.7943	.5494	.2775	0.0	WORD 6-2
0.0	.2013	.2428	.3087	.4324	.5952	.7159	.8197	.9849	1.1113	WORD 7-1
1.2088	1.2801	1.3280	1.3523	1.3244	1.1826	.9533	.6581	.3331	0.0	WORD 7-2
0.0	.0515	.0769	.1289	.2527	.4939	.7314	.9557	1.3482	1.5946	WORD 8-1
1.7332	1.8341	1.9019	1.9358	1.8942	1.6896	1.3591	.9374	.4750	0.0	WORD 8-2
0.0	.0532	.0793	.1330	.2607	.5095	.7545	.9859	1.3908	1.6450	WORD 9-1
1.7880	1.8920	1.9620	1.9970	1.9540	1.7430	1.4020	.9672	.4900	0.0	WORD 9-2
0.0	.0507	.0757	.1269	.2486	.4859	.7196	.9402	1.3264	1.5688	WORD10-1
1.7052	1.8044	1.8712	1.9045	1.8635	1.6623	1.3371	.9222	.4673	0.0	WORD10-2
0.0	.0465	.0694	.1174	.2281	.4458	.6602	.8627	1.2169	1.4394	WORD11-1
1.5645	1.6555	1.7168	1.7474	1.7098	1.5251	1.2268	.8461	.4288	0.0	WORD11-2
0.0	.0528	.0789	.1323	.2576	.4997	.7411	.9698	1.3685	1.6196	WORD12-1
1.7589	1.8600	1.9272	1.9616	1.9110	1.6956	1.3556	.9312	.4710	0.0	WORD12-2
0.0	.0528	.0789	.1323	.2576	.4997	.7411	.9698	1.3685	1.6196	WORD13-1
1.7589	1.8600	1.9272	1.9616	1.9110	1.6956	1.3556	.9312	.4710	0.0	WORD13-2
180.0	9.7	-14.70								PODORG 1
0.0	5.0	10.0	15.0	20.0	25.0	27.5	30.0	35.0	38.47	XPOD 1
3.195	3.387	3.536	3.678	3.810	3.937	3.989	3.981	3.893	3.804	PODR 1
180.0	16.7	-14.27								PODORG 2
0.0	5.0	10.0	15.0	20.0	25.0	27.5	30.0	35.0	38.47	XPOD 2
3.195	3.387	3.536	3.678	3.810	3.937	3.989	3.981	3.893	3.804	PODR 2
180.0	23.7	-13.29								POGORG 3
0.0	5.0	10.0	15.0	20.0	25.0	27.5	30.0	35.0	38.47	XPOD 3
3.195	3.387	3.536	3.678	3.810	3.937	3.989	3.981	3.893	3.804	PODR 3
171.75	11.4	-12.00								PODORG 4
0.0	3.25	5.75	8.25	10.75	13.25	15.75	18.25	23.25	28.25	XPOD 4
0.0	.626	.937	1.128	1.223	1.194	1.095	.982	.67	0.0	PODR 4
171.75	21.8	-11.0								PODORG 5
0.0	3.25	5.75	8.25	10.75	13.25	15.75	18.25	23.25	28.25	XPOD 5
0.0	.626	.937	1.128	1.223	1.194	1.095	.982	.67	0.0	PODR 5

Table B-2 - Estimated weights and balance for a baseline Mach 3.0 HSCT concept.

Item	Weight, lb	FS c.g., in.	WL c.g., in.
Wing	56 258	2050.0	85.0
Horizontal	0		
Vertical	1 101	3462.4	297.3
Fin	0		
Canard	0		
Fuselage	43 906	1920.0	103.0
Landing gear	32 326	1850.4	70.0
Nacelle	19 790	2330.0	13.0
Structure total	153 381	2016.9	79.2
Engines	50 665	2435.0	13.0
Thrust reverser	0		
Miscellaneous systems	2 341	1481.5	45.7
Fuel system	8 026	2083.9	89.5
Propulsion total	61 031	2352.2	24.3
Surface controls	7 399	2193.6	122.2
Auxiliary power unit	1 578	2600.0	50.0
Instruments	2 141	1172.4	103.0
Hydraulics	5 449	1958.6	103.0
Electrical	3 888	1293.5	103.0
Avionics	1 449	860.0	136.0
Furnishings and equipment	20 388	1842.0	
Air conditioning	6 741	1890.0	103.0
Anti-icing	215	1948.0	65.4
System and equipment total	49 246	1837.7	61.2
Weight empty	263 658	2061.1	63.1
Flight crew and baggage (2)	450	528.0	144.0
Cabin crew and baggage (7)	1 130	1842.0	98.0
Unusuable fuel	3 269	2083.9	89.5
Engine oil	914	2435.0	13.0
Passenger service	3 560	1842.0	98.0
Cargo containers	0		
Operating weight	272 981	2056.3	64.0
Passengers (250)	41 250	1842.0	98.0
Passenger baggage	11 000	1300.0	75.0
Miscellaneous items	2 565	1920.0	103.0
Cargo	0		
Zero-fuel weight	327 796	2002.9	69.0
Mission fuel	385 900	1849.0	106.1
Gross weight	713 696	1919.7	89.0

Appendix C

Description of Physical Property Data Requirements for an EZDESIT Execution

Tables C-1 through C-4 list the existing property set definitions for types of element constructions that can currently be used with EZDESIT. The format and description of the data is taken verbatim from Reference 2 and the value used for each of these items in the present study is listed.

Table C-1 - Physical property definition for an isotropic material, honeycomb plate.

FIELD	CURRENT VALUE	DESCRIPTION
1	10[a]	Material number, refer to the "matprop.prn" file
2	30	Span used to check panel buckling, in.
3	9	9 = isotropic honeycomb
4	1.0	Factor times input loads to obtain ultimate load (typically 1.0 with EAL runs done at ultimate load)
5	0.8	Panel buckling load knockdown factor (typically .8)
6	1.0	Non optimum factor (1.0 = none)
7	0.01	Minimum gage of facesheet, in.
8	1.0	Young's modulus reduction factor (1.0 = full value in "matprop.prn" file)
9	1.0	Allowable strength reduction factor (1.0 = full value in "matprop.prn" file)
10	0	"Dummy"[b]
11	0.1	Minimum core height, in.
12	3.0	Maximum core height, in.
13	0.1	Core material density, $lbs/in.^3$ (ex: aluminum = .1, routine hcbndth assumes 2% core factor)
14	0	"Dummy"
15	0	"Dummy"
16	0	"Dummy"
17	0	"Dummy"
18	0	"Dummy"
19	0	"Dummy"
20	0	"Dummy"

[a] This "material number" is for titanium.

[b] The "Dummy" parameters are only placeholders for possible code expansion.

Table C-1 - Con't.

FIELD	CURRENT VALUE	DESCRIPTION
21	0	"Dummy"
22	0	"Dummy"
23	0	"Dummy"
24	0	"Dummy"
25	0	"Dummy"
26	0.67	Factor times ultimate load to obtain limit load level (ex: = .67 if using a 1.5 safety factor)
27	0	"Dummy"
28	0	"Dummy"
29	0	"Dummy"
30	0	"Dummy"
31	0	"Dummy"
32	0	"Dummy"
33	0	"Dummy"
34	0	"Dummy"
35	0	"Dummy"

Table C-2 - Physical property definition of an isotropic material, corrugated web.

FIELD	CURRENT VALUE	DESCRIPTION
1	6[a]	Material number, refer to the "matprop.prn" file
2	30	Panel buckling span, in.
3	10	10 = corrugated web
4	1.0	Factor times input loads to obtain ultimate load
5	0.8	Panel buckling load knockdown factor typically .8 empirical/theoretical ratio)
6	2	= 1 corrugated along element x direction = 2 corrugated along element y direction
7	0.01	Minimum material gage, in.
8	0	"Dummy"[b]
9	0	"Dummy"
10	0	"Dummy"
11	0	"Dummy"
12	0	"Dummy"
13	0	"Dummy"
14	0	"Dummy"
15	0	"Dummy"
16	0	"Dummy"
17	0	"Dummy"
18	0.67	Factor times ultimate load to obtain limit load level (ex: = .67 if using 1.5 safety factor)
19	0	"Dummy"
20	0	"Dummy"
21	0	"Dummy"
22	0	"Dummy"
23	1.0	Modulus reduction factor (1.0 = full value from "matprop.prn" file)

[a] This "material number" is for titanium.

[b] The "Dummy" parameters are only placeholders for possible code expansion.

Table C-2 - Con't.

FIELD	CURRENT VALUE	DESCRIPTION
24	1.0	Allowable strength reduction factor (1.0 = full value from "matprop.prn" file)
25	1.0	Non optimum factor (1.0 = none)

Table C-3 - Physical property definition for a bar.

FIELD	CURRENT VALUE	DESCRIPTION
1	6[a]	Material number, refer to "matprop.prn" file
2	1.0	Non optimum factor
3	13	13 = bar
4	1.0	Factor times input loads to obtain ultimate load
5	0.01	Minimum area, in.^{2}
6	1.0	Modulus reduction factor (1.0 = full value from "matprop.prn" file)
7	1.0	Allowable strength reduction factor (1.0 = full value from "matprop.prn" file)
8	0	"Dummy"[b]
9	0	"Dummy"
10	0	"Dummy"
11	0.67	Factor time ultimate load to obtain limit load level (ex: = .67 if using a 1.5 safety factor)
12	0	"Dummy"
13	0	"Dummy"
14	0	"Dummy"
15	0	"Dummy'

[a] This "material number" is for titanium.

[b] The "Dummy" parameters are only placeholders for possible code expansion.

Table C-4 - Physical property definition for a planar beam.

FIELD	CURRENT VALUE	DESCRIPTION
1	6[a]	Material number, refer to the "matprop.prn" file
2	1.0	Non optimum factor (1. = none)
3	14	14 = planar beam
4	1.0	Factor times input loads to obtain ultimate load
5	0.5	Minimum cap area, $in.^2$
6	2.0	Minimum web height, in.
7	0.1	Minimum web gage, in.
8	1.0	Modulus reduction factor (1.0 = full value from the "matprop.prn" file)
9	1.0	Allowable strength reduction factor (1.0 = full value from the "matprop.prn" file)
10	0	"Dummy"[b]
11	0	"Dummy"
12	0	"Dummy"
13	0.67	Factor time ultimate load to obtain limit load level (ex: = .67.if using a 1.5 safety factor)
14	0	"Dummy"
15	0	"Dummy"
16	0	"Dummy"
17	0`	"Dummy"

---

a This "material number" is for titanium.

b The "Dummy" parameters are only placeholders for possible code expansion.

Appendix D

COMET Runstream for an All-Titanium HSCT Finite Element Model

An abbreviated listing of a COMET runstream, called "tb.dat", that was submitted for structural resizing of a candidate Mach 3.0 all-titanium HSCT finite element model is presented in this Appendix.

```
*def/i ns_common=200000
*open 1 ti.101 /new
*set echo=off
*add genutil.prc
[XQT TAB
START   398
TITLE 'ALL TITANIUM HSCT MODEL 7/30/91 4:30
MATC
    1   15945143. 0.31 0.000  0.481710E-05  0.481710E-05    0.
    2   15945143. 0.31 0.000  0.481710E-05  0.481710E-05    0.
NSW
     1     0.00167
     2     0.00417
     3     0.00333
     .
     .
     .
   135     0.00972
   136     0.01111
   137     0.02917
 JLOC
       1            30.00000            0.00000          -7.41960
       2            30.00000           11.33280          -7.19358
       3            30.00000            0.00000           0.82680
       .
       .
       .
     396          3480.00000           10.18640         -13.54595
     397          3480.00000            5.09320         -10.82704
     398          3480.00000            0.00000         -10.02000
 MREF
 FORMAT=2
     1    1      0.00000       0.00000       0.00000
 BC
     1     0.010
     2     0.026
     3     0.012
     .
     .
     .
    39     0.043
```

```
  40      0.042
  41      0.030
BD
   1    1.2000    1.0000    0.0000    1.0000   -1.0000    7.5000
   2    1.2920    2.1070    0.0000    1.4500   -1.4500    5.1720
   3    1.4850    3.5250    0.0000    1.8500   -1.8500    3.2960
   .
   .
   .
   9    1.6590    4.1210    0.0000    1.8500   -1.8500    3.2960
  10    1.5540    3.5040    0.0000    1.7500   -1.7500    3.6630
  11    1.8680    5.6450    0.0000    2.1000   -2.1000    2.5510
SA
FORMAT=COUPLED
NMAT=     1
   1  45.5       45.5       45.5        0.          0.          0.       )
  45.5       45.5       45.5       50.0        50.0        50.0       )
  45.5       45.5       45.5      -50.0       -50.0       -50.0
 0.388E+06  0.120E+06  0.388E+06   0.          0.        0.134E+06     0.      )
   0.         0.       0.324E+06   0.          0.          0.        0.101E+06 )
 0.324E+06    0.         0.        0.          0.          0.        0.112E+06
NMAT=     1
   2  31.3       31.3       31.3        0.          0.          0.       )
  31.3       31.3       31.3       29.2        29.2        29.2       )
  31.3       31.3       31.3      -29.2       -29.2       -29.2
 0.565E+06  0.175E+06  0.565E+06   0.          0.        0.195E+06     0.      )
   0.         0.       0.657E+06   0.          0.          0.        0.204E+06 )
 0.657E+06    0.         0.        0.          0.          0.        0.227E+06
NMAT=     1
   3  50.0       50.0       50.0        0.          0.          0.       )
  50.0       50.0       50.0       161.        161.        161.       )
  50.0       50.0       50.0      -161.       -161.       -161.
 0.353E+06  0.109E+06  0.353E+06   0.          0.        0.122E+06     0.      )
   0.         0.       0.352E+05   0.          0.          0.        0.109E+05 )
 0.352E+05    0.         0.        0.          0.          0.        0.122E+05
   .
   .
   .
NMAT=     2
 154    0.         0.         0.          0.          0.          0.       )
   0.         0.         0.        0.          0.          0.       )
   0.         0.         0.        0.          0.          0.
 0.770E+06  0.298E+05  0.192E+06 -10.0       -10.0       0.962E+05   10.0      )
  10.0      -10.0      0.157E+06  10.0        10.0       -10.0       0.122E+05 )
 0.393E+05  -10.0      -10.0       10.0       -10.0       -10.0       0.197E+05
NMAT=     2
 155    0.         0.         0.          0.          0.          0.       )
   0.         0.         0.        0.          0.          0.       )
   0.         0.         0.        0.          0.          0.
 0.385E+06  0.149E+05  0.962E+05 -10.0       -10.0       0.481E+05   10.0      )
  10.0      -10.0      0.301E+05  10.0        10.0       -10.0       0.621E+04 )
 0.200E+05  -10.0      -10.0       10.0       -10.0       -10.0       0.100E+05
NMAT=     2
```

```
 156     0.        0.        0.        0.        0.        0.      )
   0.        0.        0.        0.        0.        0.      )
   0.        0.        0.        0.        0.        0.
 0.292E+07 0.113E+06 0.729E+06 -10.0     -10.0     0.365E+06 10.0    )
  10.0     -10.0     0.543E+06  10.0      10.0     -10.0     0.421E+05 )
 0.136E+06 -10.0     -10.0      10.0     -10.0     -10.0     0.679E+05
CON=  1
ZERO  1:   189
ZERO  3:   189
ZERO  3:   237
SYMMETRY PLANE=2
RMASS
#PATRAN NODAL TEMP SET        101
    93   2237.800
    96   2367.600
    98   2152.700
   118    864.600
   121    964.800
   123    991.600
   126    941.800
#PATRAN NODAL TEMP SET        102
    93   2223.400
    96   2427.200
    98   1510.200
   118    699.900
   121   1908.000
   123   2102.100
   126   1219.100
     .
     .
     .
#PATRAN NODAL TEMP SET        240
   146    585.25
   160    585.25
   218   5279.38
   235   5279.38
   238   1824.58
   252   1824.58
    91    165.66
   103    165.66
   117    806.34
   130    806.34
   193    878.29
   214    878.29
[XQT ELD
E23
NMAT=   1: NSECT=     1: NNSW=    1
   58   81    0     0 #el no     1
NMAT=   1: NSECT=     1: NNSW=    1
   57   80    0     0 #el no     2
NMAT=   1: NSECT=     1: NNSW=    1
   60   83    0     0 #el no     3
    .
```

```
    .
    .
NMAT=   1: NSECT=     1: NNSW=   1
   50   43    0    0 #el no   575
NMAT=   1: NSECT=     1: NNSW=   1
   48   42    0    0 #el no   576
NMAT=   1: NSECT=     1: NNSW=   1
   47   37    0    0 #el no   577
E24
NMAT=   1: NSECT=     1: NNSW=  18: NREF=     1
  398  397    0    0 #el no   578
NMAT=   1: NSECT=     1: NNSW=  18: NREF=     1
  397  396    0    0 #el no   579
NMAT=   1: NSECT=     1: NNSW=  18: NREF=     1
  396  395    0    0 #el no   580
    .
    .
    .
NMAT=   1: NSECT=     1: NNSW=  18: NREF=     1
  211  208    0    0 #el no   804
NMAT=   1: NSECT=     1: NNSW=  18: NREF=     1
  232  229    0    0 #el no   805
NMAT=   1: NSECT=    11: NNSW=  28: NREF=     1
  249  247    0    0 #el no   806
E33
NMAT=   1: NSECT=     1: NNSW=  29
  162  147  175    0 #el no   807
NMAT=   1: NSECT=     2: NNSW=  30
  161  145  163    0 #el no   808
NMAT=   1: NSECT=     3: NNSW=  31
  147  120  151    0 #el no   809
    .
    .
    .
NMAT=   2: NSECT=    11: NNSW=  39
  120  116  118    0 #el no   836
NMAT=   2: NSECT=    11: NNSW=  39
   95   92   93    0 #el no   837
NMAT=   2: NSECT=    11: NNSW=  39
   73   69   72    0 #el no   838
E43
NMAT=   1: NSECT=    14: NNSW=  41
   64   87   89   66 #el no   839
NMAT=   1: NSECT=     8: NNSW=  36
   63   86   88   65 #el no   840
NMAT=   1: NSECT=     7: NNSW=  35
   66   89   90   67 #el no   841
    .
    .
    .
NMAT=   2: NSECT=   143: NNSW=  39
  189  210  207  188 #el no  1312
NMAT=   2: NSECT=   143: NNSW=  39
```

```
  210  231  225  207 #el no  1313
NMAT=   2: NSECT=   143: NNSW=  39
  231  237  236  225 #el no  1314
[XQT E
 T= 1.-20, .05, 1.-5, 1.-1, 20., 1.-4, 1.-4, 1.-4
[XQT EKS
[XQT TOPO
[XQT K
[XQT M
[XQT AUS
MAS=SUM(CEM,RMAS)
[XQT INV
RESET CON=    1
[XQT AUS
ALPHA: CASE TITL    1
1'wing tip loading
SYSVEC: APPL FORC    1
J=   58:      0.          0.      0.2500E+05    0.          0.          0.
J=   64:      0.          0.      0.2500E+05    0.          0.          0.
*call forcesum (lib=(1); set=(  1); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL    2
1'aero case 1
ELDATA: PRES E33 2 1
G=1: E=   2:  0.495479     0.495479     0.495479
G=1: E=   4:  0.476364     0.476364     0.476364
G=1: E=   6:  0.459449     0.459449     0.459449
G=1: E=   8:  0.429918     0.429918     0.429918
G=1: E=  10:  0.396372     0.396372     0.396372
ELDATA: PRES E43 2 1
G=1: E=   2:  0.372723     0.372723     0.372723     0.372723
G=1: E=   4:  0.367201     0.367201     0.367201     0.367201
G=1: E=   6:  0.460492     0.460492     0.460492     0.460492
      .
      .
      .
G=1: E= 132:  0.448571     0.448571     0.448571     0.448571
G=1: E= 134:  0.623787     0.623787     0.623787     0.623787
[XQT EQNF
RESET SET=    2
[XQT DCU
CHANGE 1 EQNF FORC    2 1 APPL FORC    2 1
*call forcesum (lib=(1); set=(  2); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL    3
1'aero case 2
ELDATA: PRES E33 3 1
G=1: E=   2:  0.664626     0.664626     0.664626
G=1: E=   4:  0.594172     0.594172     0.594172
G=1: E=   6:  0.586386     0.586386     0.586386
G=1: E=   8:  0.633090     0.633090     0.633090
G=1: E=  10:  0.754930     0.754930     0.754930
ELDATA: PRES E43 3 1
```

```
G=1: E=   2:  0.550738E-01 0.550738E-01 0.550738E-01 0.550738E-01
G=1: E=   4: -0.919826E-01 -0.919826E-01 -0.919826E-01 -0.919826E-01
G=1: E=   6:  0.129170     0.129170     0.129170     0.129170
     .
     .
     .
G=1: E= 130:  0.869722     0.869722     0.869722     0.869722
G=1: E= 132:  0.985188     0.985188     0.985188     0.985188
G=1: E= 134:  0.789944     0.789944     0.789944     0.789944
[XQT EQNF
RESET SET=    3
[XQT DCU
CHANGE 1 EQNF FORC    3 1 APPL FORC    3 1
*call forcesum (lib=(1); set=(  3); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL     4
1'aero case 3
ELDATA: PRES E33 4 1
G=1: E=   2:  0.336062     0.336062     0.336062
G=1: E=   4:  0.276674     0.276674     0.276674
G=1: E=   6:  0.249004     0.249004     0.249004
G=1: E=   8:  0.233692     0.233692     0.233692
G=1: E=  10:  0.245430     0.245430     0.245430
ELDATA: PRES E43 4 1
G=1: E=   2:  0.139290     0.139290     0.139290     0.139290
G=1: E=   4:  0.969320E-01 0.969320E-01 0.969320E-01 0.969320E-01
G=1: E=   6:  0.960526E-01 0.960526E-01 0.960526E-01 0.960526E-01
     .
     .
     .
G=1: E= 130:  0.307940     0.307940     0.307940     0.307940
G=1: E= 132:  0.312035     0.312035     0.312035     0.312035
G=1: E= 134:  0.412321     0.412321     0.412321     0.412321
[XQT EQNF
RESET SET=    4
[XQT DCU
CHANGE 1 EQNF FORC    4 1 APPL FORC    4 1
*call forcesum (lib=(1); set=(  4); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL     5
1'aero case 4
ELDATA: PRES E33 5 1
G=1: E=   2:    1.51809      1.51809      1.51809
G=1: E=   4:    1.44913      1.44913      1.44913
G=1: E=   6:    1.40116      1.40116      1.40116
G=1: E=   8:    1.29837      1.29837      1.29837
G=1: E=  10:    1.18715      1.18715      1.18715
ELDATA: PRES E43 5 1
G=1: E=   2:  0.983358     0.983358     0.983358     0.983358
G=1: E=   4:  0.971026     0.971026     0.971026     0.971026
G=1: E=   6:    1.37643      1.37643      1.37643      1.37643
     .
     .
```

```
     .
G=1: E= 130:  1.62700     1.62700     1.62700     1.62700
G=1: E= 132:  1.38076     1.38076     1.38076     1.38076
G=1: E= 134:  2.01220     2.01220     2.01220     2.01220
[XQT EQNF
RESET SET=   5
[XQT DCU
CHANGE 1 EQNF FORC    5 1 APPL FORC    5 1
*call forcesum (lib=(1); set=(  5); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL     6
1'aero case 5
ELDATA: PRES E33 6 1
G=1: E=   2:  1.63482     1.63482     1.63482
G=1: E=   4:  1.36996     1.36996     1.36996
G=1: E=   6:  1.21555     1.21555     1.21555
G=1: E=   8:  1.09577     1.09577     1.09577
G=1: E=  10:  1.07144     1.07144     1.07144
ELDATA: PRES E43 6 1
G=1: E=   2: 0.609049    0.609049    0.609049    0.609049
G=1: E=   4: 0.405767    0.405767    0.405767    0.405767
G=1: E=   6: 0.469569    0.469569    0.469569    0.469569
     .
     .
     .
G=1: E= 130:  1.47321     1.47321     1.47321     1.47321
G=1: E= 132:  1.37584     1.37584     1.37584     1.37584
G=1: E= 134:  2.15222     2.15222     2.15222     2.15222
[XQT EQNF
RESET SET=   6
[XQT DCU
CHANGE 1 EQNF FORC    6 1 APPL FORC    6 1
*call forcesum (lib=(1); set=(  6); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL    50
1'1.0g inertial load
[XQT AUS
R=RIGID( 225)
DEFINE F=1 R AUS 1 1 3 3
MX2=PRODUCT(MAS,F)
APPL FORC 50 1 =UNION(  -1.00 MX2)
*call forcesum (lib=(1); set=( 50); con=(1); jnt=(225))
[XQT AUS
ALPHA: CASE TITL    60
1'2.5g inertial load
[XQT AUS
R=RIGID( 225)
DEFINE F=1 R AUS 1 1 3 3
MX2=PRODUCT(MAS,F)
APPL FORC 60 1 =UNION(  -2.50 MX2)
*call forcesum (lib=(1); set=( 60); con=(1); jnt=(225))
[XQT AUS
ALPHA: CASE TITL    51
```

```
1'load case 1
[XQT aus
DEFINE AA=1 APPL FORC    2 1
DEFINE BB=1 APPL FORC   50 1
APPL FORC   51   1 =SUM( 1.0000 AA,  0.7311 BB)
*call forcesum (lib=(1); set=( 51); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL    52
1'load case 3
[XQT aus
DEFINE AA=1 APPL FORC    3 1
DEFINE BB=1 APPL FORC   50 1
APPL FORC   52   1 =SUM( 1.0000 AA,  0.9708 BB)
*call forcesum (lib=(1); set=( 52); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL    53
1'load case 3
[XQT aus
DEFINE AA=1 APPL FORC    4 1
DEFINE BB=1 APPL FORC   50 1
APPL FORC   53   1 =SUM( 1.0000 AA,  0.4928 BB)
*call forcesum (lib=(1); set=( 53); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL    61
1'load case 4
[XQT aus
DEFINE AA=1 APPL FORC    5 1
DEFINE BB=1 APPL FORC   60 1
APPL FORC   61   1 =SUM( 1.0000 AA,  0.9220 BB)
*call forcesum (lib=(1); set=( 61); con=(1); jnt=(1))
[XQT AUS
ALPHA: CASE TITL    62
1'load case 5
[XQT aus
DEFINE AA=1 APPL FORC    6 1
DEFINE BB=1 APPL FORC   60 1
APPL FORC   62   1 =SUM( 1.0000 AA,  0.9827 BB)
*call forcesum (lib=(1); set=( 62); con=(1); jnt=(1))
[XQT SSOL
RESET CON=    1 SET=   51
[XQT SSOL
RESET CON=    1 SET=   52
[XQT SSOL
RESET CON=    1 SET=   53
[XQT SSOL
RESET CON=    1 SET=   61
[XQT SSOL
RESET CON=    1 SET=   62
[XQT EXIT
```

Appendix E

Iterative Procedure for Balancing Airplane Load Case No. 1

The process used to balance the loads on the airplane for trimmed flight is described in this Appendix. First, an initial structural resizing analysis was conducted to establish the total weight (structural and non-structural) of the airplane and the lift component of the aerodynamic pressures. Then, three or more iterations were performed to adjust the aerodynamic lift and balance load for a trimmed airplane.

<u>Initial Execution</u>

This initial COMET execution is for determining the lift component of the aerodynamic pressures and the magnitude of the total weight so that factors can be determined for matching these values to the design loads. The lift component and total weight are determined during the execution by a procedure called "forcesum". This procedure determines the summation of forces and moments about a specified reference point for a specified set of loads (the reference point is node 225 for the present study). These resultants, for the symmetrical half of the airplane, are written to an output (or log) file that is created during program execution and are as follows:

Aerodynamic Lift (load case 2)	202,500 lbs.
Inertial Force (load case 50)	381,400 lbs.

The weight fraction used for the initial resizing exercise is determined as follows using the flight design gross weight and maximum gross weight for a total airplane given in Tables A-1 and A-2 of Appendix A, respectively:

Design GW/Maximum GW = 494,000/675,000 = 0.7311.

Multiplying the inertial force by the weight factor and adding the aerodynamic lift results in an imbalance of 152,640 lbs. (load set 51) in the downward direction; which requires an increase in the aerodynamic lift to correct. However, since the non-structural weights of Appendix B were used in formulating the finite element model, it was decided that the corresponding maximum gross weight of 713,696 lbs. would be the baseline weight for the present study. Therefore, a revised design gross weight for succeeding iterations is

(.7311)(713,696) = 521,783 lbs.

First Iteration

This COMET execution is performed to obtain a balance of the inertial force and the aerodynamic lift component. Using the inertial force (which is based on a 1.0 g maneuver) of the initial execution, the calculated maximum gross weight is (2)(381,400) = 762,800 lbs. The new weight fraction for this iteration is

Design GW/Maximum GW = 521,783/762,800 = 0.6840.

The aerodynamic lift, as given by the initial execution, is (2)(202,500) = 405,000 lbs. Therefore, the aerodynamic fraction required to balance the forces is

Design GW/Aerodynamic Lift = 521,783/405,000 = 1.2884.

Second Iteration

The unbalanced moment about the Y-axis at node 225 due to the offset of the center of gravity and the center of pressure is given by the first iteration (load set 51) as 21,100,000 in.-lbs. A balance load is applied at node 391 (an arbitrary selection) which is 1531.46 inches aft of node 225. The balance load is

21,100,000/1531.46 = 13,778 lbs.

To account for this additional vertical force, the aerodynamic fraction is modified as follows:

[521,783 - (2)(13,778)]/405,000 = 1.2203.

Third Iteration

The reduction of the aerodynamic lift by the balance load causes a secondary change in the moment imbalance between the lift and the inertial loads. The unbalanced moment from the second iteration is -278,500 in.-lbs which requires a reduction in the balance load by 182 lbs (278,500/1531.46) to 13,596 lbs (13,778 - 182) and another modification of the aerodynamic fraction as follows:

$$[521{,}783 - (2)(13{,}596)] / 405{,}000 = 1.2212.$$

No further iterations were performed.

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An analysis has been performed pertaining to the structural resizing of a candidate Mach 3.0 High-Speed Civil Transport (HSCT) conceptual design using a computer program called EZDESIT. EZDESIT is a computer program which integrates the PATRAN finite element modeling program to the COMET finite element analysis program for the purpose of calculating element sizes or cross sectional dimensions. The purpose of the present report is to document the procedure used in accomplishing the preliminary structural sizing and to present the corresponding results.

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